R E S T R I C T E D C I R C U L A T I O N

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Use of the degree-day idea when the response of the organism to temperature is complex.

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1. Introduction.

The response of a plant to temperature is often represented by the scheme of fig 1. No growth occurs below temperature T_o, known as the base temperature. Above T_o, growth is assumed proportional to temperature. Clearly, such a picture is likely to be an oversimplification. The change from no growth to growth is unlikely to be quite so abrupt as shown, and the increase in response with temperature will not be sustained indefinitely. Still, the picture of fig 1 has served well for a remarkable variety of plants, particularly in temperate climates such as that of Britain. In practical situations where we are concerned with the growth of plants over a period of time, it is usual to integrate the response over time t for positive values only of $(T - T_o)$, day by day. The result summed over the period of interest is known as accumulated temperature, the usual units being degree-days.

In Ag Mem 679 a more complex response to temperature was encountered (as shown in fig 2) for the sporulation of the fungus Cercosporella herpotrichiodes. In this case the integrated response over the day, in units of degree-hours, is known as the Daily Thermal Sporulation Coefficient (DTSC). It was found possible to express the DTSC as a combination of accumulated temperatures above different bases, the bases corresponding to the points (0° and 10°C) at which the curve of fig 2 changes slope. This suggested the possibility of generalising the result to any continuous response curve composed of linear segments.

2. The Generalised Response Curve.

Fig 3 shows a theoretical response curve, rising from base T_o by N linear segments of slope a_n, each terminating at break-point T_n. The successive gradients increase in the diagram for the sake of clarity, but need not do so. The response at any temperature may be expressed in terms of the contributions of the first gradient (the usual degree-day idea) plus a series of correction terms for the gradient changes in successive segments. Thus the response R at temperature T in fig 3 is given by

$$\begin{aligned} R &= BD + DE \\ &= BD + (CE - CD) \\ &= a_1 (T - T_o) + a_2 (T - T_1) - a_1 (T - T_1) \\ &= a_1 (T - T_o) + (a_2 - a_1) (T - T_1) \end{aligned}$$

generally,

$$\begin{aligned} R &= a_1 (T - T_o) + (a_2 - a_1) (T - T_1) + (a_3 - a_2) (T - T_2) \\ &\quad \cdots\cdots + (a_n - a_{n-1}) (T - T_{n-1}) \end{aligned}$$

$$R = \sum_{o}^{N-1} (a_{n+1} - a_n) (T - T_n) \qquad (1)$$

where $a_o = 0$ by definition, and the summation is taken over positive values only of $(T - T_n)$.

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The accumulated temperature above the nth base is defined by

$$A_n = \int (T - T_n)\, dt \qquad (2)$$

where the integral is taken over 24 hours and positive values only of $(T - T_n)$.

Integrating (1) term-by-term with respect to t over 24 hours and substituting (2) gives

$$\int R\,dt = \sum_{0}^{N-1} (a_{n+1} - a_n)\, A_n \qquad (3)$$

3. An Application of the General Result

In the case of the eyespot function whose curve is shown in fig 2

$R \equiv$ EUV (equivalent unit value)

$\int R\,dt \equiv$ DTSC (daily thermal sporulation coefficient)

$N = 2$

$a_o = 0$ $\qquad T_o = 0^oC$

$a_1 = 1$ $\qquad T_1 = 10^oC$

$a_2 = -1$

a_3 etc $= 0$

Putting these values into (3) gives

$$DTSC = (1 - 0)\, A_o + (-1 - 1)\, A_1$$

$$DTSC = A_o - 2A_1 \qquad (4)$$

or writing the bases explicitly and converting from units of degree-days to degree-hours

$$DTSC = 24 \left[(^oC \text{ days above } 0^oC) - 2(^oC \text{ days above } 10^oC) \right] \qquad (5)$$

This is the result obtained by a special argument in Ag Mem 679.

4. Discussion.

It has been shown that if the response curve of an organism to temperature can be represented by a number of continuous linear segments, then the time-integrated response can be calculated as the sum of a number of accumulated temperature terms above different bases, the bases corresponding to the break-points in the response curve. To some, the representation of a non-linear response by a linear approximation may appear retrograde. It has the advantage that use can be made of rapid and well-established methods for estimating degree-days from either monthly mean or daily maximum and minimum temperatures. This is particularly valuable in those awkward but practically important cases, when the daily wave of temperature is fluctuating about a break-point in the response curve.

Any comments or suggestions on this paper should be referred to the author.

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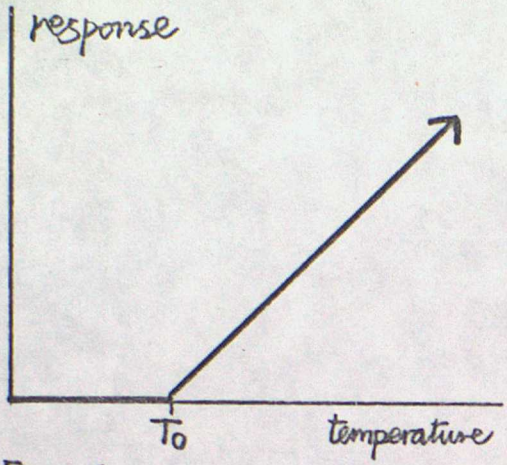

Fig 1. Simple temperature response

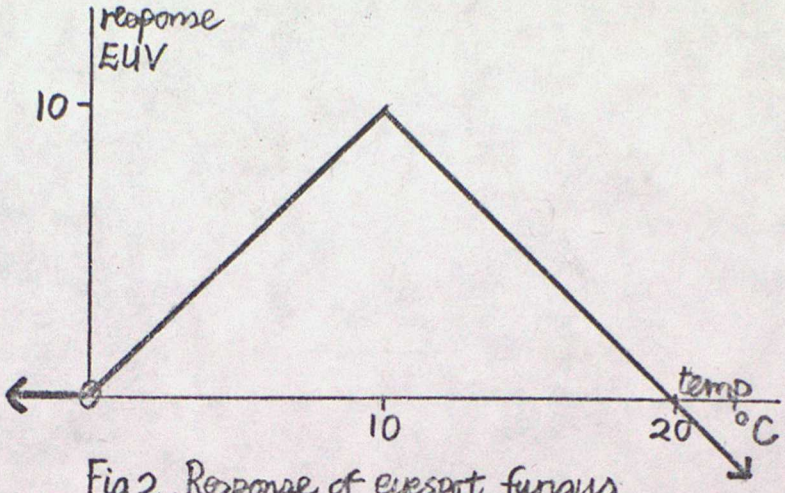

Fig 2. Response of eyespot fungus

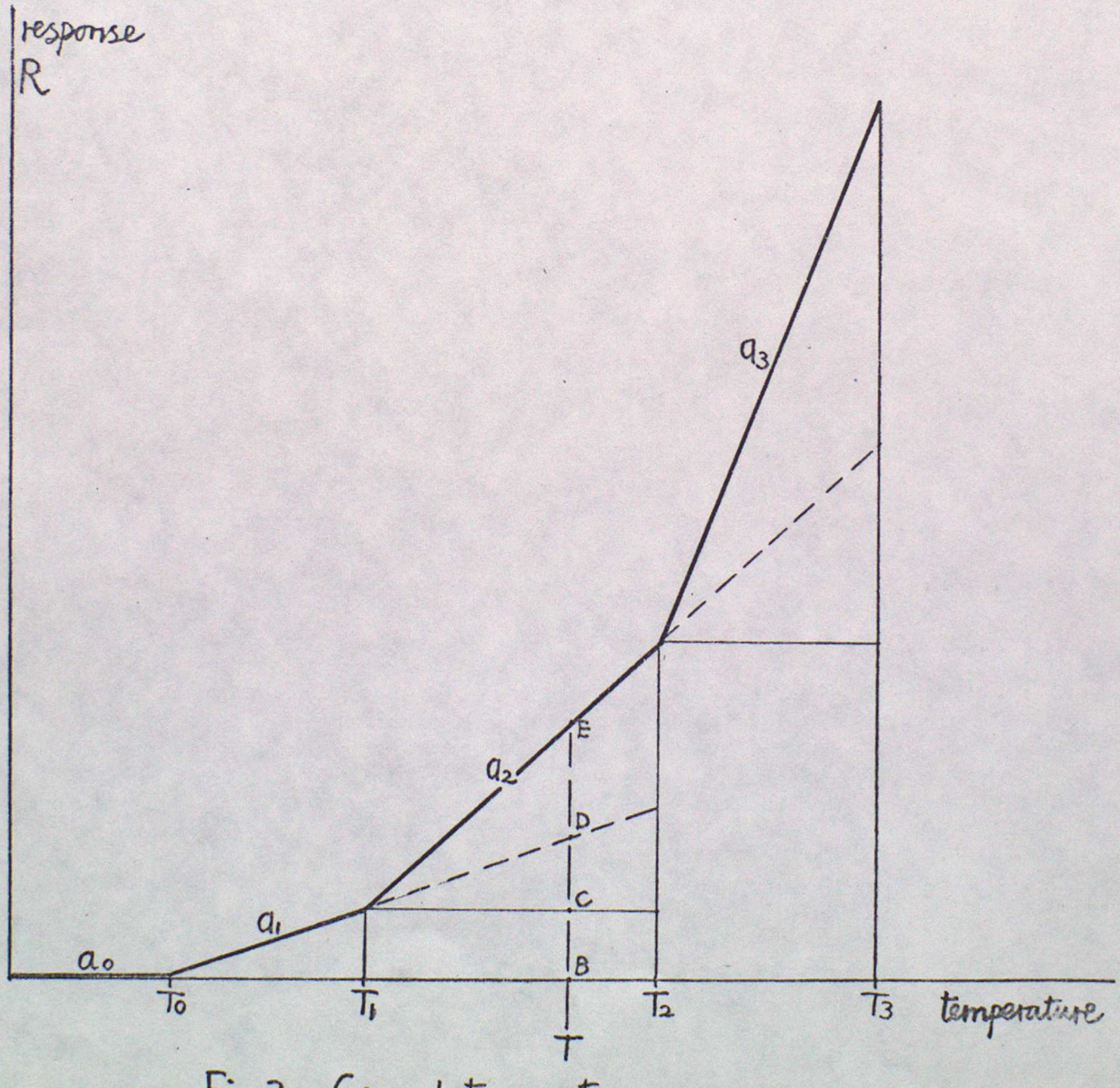

Fig 3. General temperature response